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An Algorithm to Detect Point on Wave Initiation of Voltage Sag by Fundamental Equation

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***Abstract*— This paper presents an algorithm for detection and characterization of voltage sag on transmission and distribution lines. A Discrete Wavelet Transform is utilized to extract voltage sag disturbances from fundamental 50 Hz, which detects magnitude, duration, and Point on Wave initiation of voltage sag. This algorithm is simulated in MATLAB and the results are presented at various magnitudes and Point on Wave initiations.**

***Index Terms*— Power quality, Point on Wave initiation, Voltage sag, Discrete Wavelet Transform.**

I. Introduction

Power quality has become an important issue over the past several years [1]. One of most important power quality issues on transmission and distribution lines is the voltage sag. It causes severe effects to end users [1, 2]. In general, sag characteristics, e.g. magnitude and duration are typically determined using an RMS envelope. For some types of equipments an accurate determination of fault initiation and clearing time is needed to properly determine other characteristics such as Point on Wave, phase angle jump to verify proper operation of equipment [2, 3]. Accurate time localization or Point on Wave initiation of sag disturbance is one of the important first step in accurately determining some of these additional parameters. IEEE standard 1346, 1998 states that information about phase shift and Point on Wave values are not typically available in sag environment data. Therefore for compatibility evaluation it is recommended that phase shift and Point on Wave initiation should not considered. Reference [3], particularly describes that the behavior of contactor not only depends on magnitude and duration of voltage sag but also the Point on Wave initiation where voltage sag occurs. This paper describes the definition of voltage sag characteristics, algorithm for characterization of voltage sag and results by using MATLAB 7.1 software.

II. Voltage Sag Characteristics

The voltage sag is defined by IEEE Standard 1159-1995, IEEE Recommended Practice for Monitoring Electric Power Quality, is "a decrease in RMS voltage or current at the power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage". Typical values are between 0.1 p.u. and 0.9 p.u. and typical fault clearing time ranges from three to thirty cycles Another definition as given in IEEE Std. 1159, 3.1.73 is "A variation of the RMS value of the voltage from nominal voltage for a time greater than 0.5 cycles of the power frequency but less than or equal to 1 minute. Figure 1 and 2 shows RMS phase voltage and instantaneous phase voltage waveform during the sag. These are two most frequently used representations of an individual sag event.

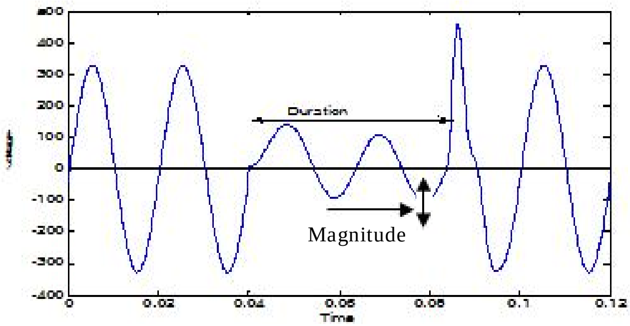

Figure 1 Voltage sag represented by the RMS values of phase voltages

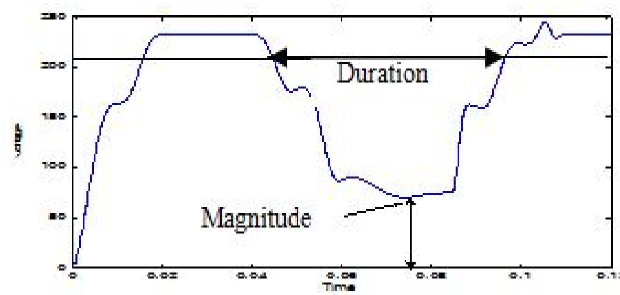

Figure 2 Voltage sag represented by the instantaneous values of phase voltage

This paper presents an algorithm, which will give the characteristics of voltage sag using DWT with RMS and instantaneous waveform. The algorithm is tested with the waveforms obtained from simulation model of voltage sag generator, developed in MATLAB 7.1, using SymPowerSystem toolbox. Following are the important characteristics to which equipments are sensitive.

Voltage Sag Magnitude
Duration
C. Point on wave
D. Missing Voltage
E. Phase-Angle Jump

III. Literature Review

Duration and magnitude are the parameters that have been normally used to classify voltage sags. From the References 3,6,7and 8 it is observed that the point-in-wave of voltage sag initiation has impact on the behavior of equipments. Similarly some techniques are explained for detection of

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voltage sag characteristics.

From the literature review it is observed that RMS evaluation method, missing voltage technique wavelet transform technique is implemented to calculate the characteristics like depth, duration and missing voltage of voltage sag as well as start and end of voltage sag.

Voltage sag magnitude, duration, shape, and type are the "RMS sag characteristics." They are directly related to RMS voltage values and can be clearly seen and identified from the RMS voltage plot. Phase shift and the point on wave at the sag initiation and ending are two sag characteristics that cannot be identified from the RMS plot. They, together with the transients and complex voltages (phasors), are the "instantaneous sag characteristics" that can be identified on the instantaneous voltage waveform plot. The extreme case is under-voltage transients, which may not be registered at all if only the RMS phase voltage values are used for the description of voltage reduction events. Full and exact assessment of the equipment sensitivity to voltage sags is possible only if all sag characteristics are known. It is clear for this purpose; both the RMS and the instantaneous waveform plot should be available. If only one of these two plots is used for sag representation, some of the sag characteristics will be lost [4].

IV. Approaches to detect Point on Wave initiation

Some approaches are described [2,5,6], in which The waveform envelope method is an alternative approach that attempts to determine the sag start and end times from the instantaneous phase voltage waveform. For a given sag event, the pre-fault steady state voltage and during sag voltage are captured. Then both are examined at a point where the waveform deviated from ideal. Next, two sets of additional waveforms, one at 10% and 5%, are calculated to form an "envelope" around the ideal voltage waveform. If there is no disturbance, the phase voltage stays within the envelopes, and no event is detected. In the presence of sag, however, the voltage falls outside of one or both envelopes, and the event is detected.

The same approach is described in [2] where 10 and 5% waveform envelopes are used for the identification of point of initiation values and only the 10% waveform envelop for the identification of point-of-ending values. The reason for using only the 10% waveform envelope for the identification of point-of-ending values is that 'most sags do not recover to within 5% in the data set intervals'. Measurement of the point of initiation is triggered when during-sag voltage falls below the 10% envelope. After triggering, the point of initiation is then identified by backtracking and comparing during-sag voltage with the 5% envelope. Point on Wave initiation characteristics of voltage sag can be identified or at least estimated by performing simple inspection of the recorded voltage waveform. Regardless of whether it is visual or automated, the identification of point-on-wave characteristics is as easier as the sag is deeper and the transition from pre-sag to during-sag voltage and from during-sag to post-sag voltage faster.

According to reference [5, 6, 7], DWT detects voltage sag and its start time as close to 100%. Therefore by application of DWT it also possible to detect Point on Wave initiation. This paper presents an algorithm for voltage sag characteristics such as magnitude, duration and Point on Wave initiation using RMS, instantaneous waveform and DWT explained in next section.

V. Voltage Sag Generator Model

A simulation model as shown in figure 3, is developed to generate voltage sag. To obtain the voltage sag three-phase single line to ground fault is created. The voltage sag of magnitudes 15, 20, 30…80% and Point on Wave initiation at steps of 15º differences from 0º to 90º is generated in the simulation model. From the simulation model RMS and instantaneous waveforms are captured across the load. By using RMS waveform voltage sag magnitude and duration are calculated according definition mentioned in the IEEE standard 1159-1998. The magnitude is calculated as the percentage of the remaining voltage during the event and the duration is by looking for RMS voltage levels that drops below a specified threshold.

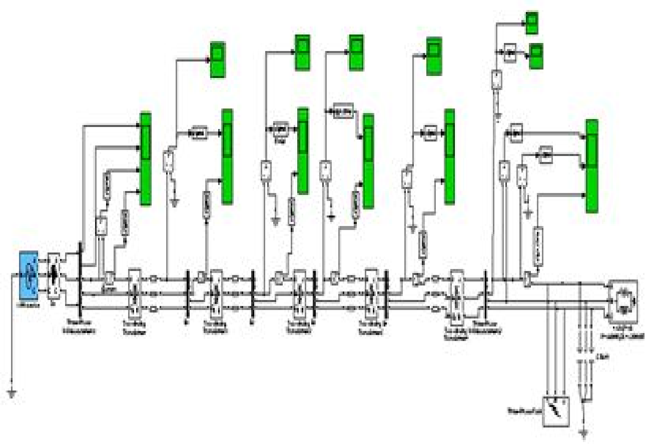

Figure 3 Voltage sag Generator model

VI. Fundamental Equation

A software program is developed in [7,8] to detect point on wave initiation at 0,10,20, …..80% voltage sag and at 0,15,30,…..90degree point on wave initiation using DWT. The algorithm has following conclusion for the simulated data.

-Considering one cycle window before RMS voltage start, to detect start of voltage sag using DWT Daubechies wavelet (db4) is used. This method is capable to identify start and stop times close to 100% of the disturbance analyzed, and it produces results as good as or better than those obtained from RMS voltage method.

-The Discrete wavelet transform procedure is used to determine the Point-on-wave initiation as it detects sag start accurately[7,8].

Now if start is known and its previous positive zero crossing point on instantaneous waveforms is known then we can find the Point-on-wave initiation if timedifference

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between sag start and zero crossing is converted to the angle by fundamental formula.

Results obtained from the DWT method to detect point-on-wave initiation has draw back that as the voltage sag becomes shallow the Point on wave initiation has more error. It is proved that Point-on-wave initiation is the characteristics which cannot be identified from RMS plot as well as from DWT method implemented in this algorithm. This is a characteristic which can be an "instantaneous sag characteristics", which can be identified on the instantaneous voltage waveform plot. Figure 4 show the result of direct comparison of ideal instantaneous waveform and instantaneous voltage sag waveform. The Point-on-wave initiation can be detected at the point at which two waveform deviates as shown in figure 4.

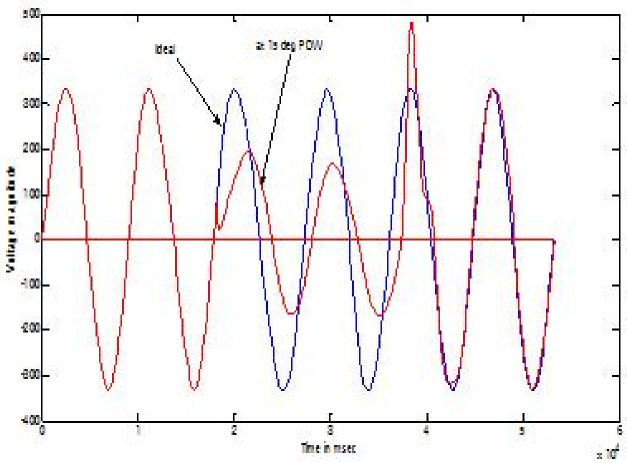

Figure 4: Direct comparison of ideal and Voltage sag Waveform

VII. Algorithm To Find Pow Initiation Of Voltage Sag By Using Dwt Method

Fundamental equation uses a basic equation of Alternating voltage i.e.

$$Vi = Vm \sin \theta \tag{7.1}$$

Where Vi = instantaneous voltage

Vm= peak voltage

$\theta = \omega t$ =pahse angle,

$\omega = 2 \Pi f$ = angular frequency

So from this fundamental equation Point-on-wave initiation is determined with assumption that Vi is voltage sag start instant (phase angle), Vm is the peak voltage of the ideal waveform.

Point-on-wave initiation i.e. $\theta = Sin^{-1} \frac{Vi}{Vm}$ (7.2)

Step 1 Define difference in time and corresponding angel by considering constant frequency.

Step 2 Find zero crossing time before start of voltage sag.

Step 3 Compare Sag waveform with ideal waveform to find voltage sag initiation point.

Is Ideal waveform is same as Sag waveform

Yes: Continue

No: display time in sec at fault instant.

Step 4 Calculate frequency of the waveform.

Step 5 Find POW initiations of voltage sag using (7.2)

Results for Point-on-wave initiation using above technique are as shown in Table I.

Table I. Results Of An Algorithm To Detect Point On Wave Initiation Using DWT

Voltage_Sag_Magnitude InPercent	Actual POW	POW initiation By Fundamentl Equation Method	Error in Degree
%	Degree	Deg.	
15.5337	0	-0.0052	0.0052
15.5166	15	14.9952	0.0048
15.4797	30	29.9924	0.0076
15.4725	45	44.9927	0.0073
15.5768	60	59.9923	0.0077
15.8876	75	74.9847	0.0153
15.5327	90	89.4664	0.5336
19.9723	0	-0.0033	0.0033
19.9878	15	15.0015	-0.0015
20.0477	30	29.9968	0.0032
20.1891	45	44.9971	0.0029
20.4716	60	59.9855	0.0145
20.9592	75	74.9728	0.0272
20.0832	90	89.3695	0.6305
30.0391	0	-0.0033	0.0033
30.0853	15	15.0015	-0.0015
30.2386	30	29.9968	0.0032
30.5253	45	44.9971	0.0029
30.9748	60	59.9855	0.0145
30.5614	75	74.9728	0.0272
29.1159	90	89.3695	0.6305
40.3547	0	-0.0033	0.0033
40.3982	15	15.0015	-0.0015
40.5496	30	29.9968	0.0032
40.8308	45	44.9971	0.0029
41.2665	60	59.9855	0.0145
39.2506	75	74.9728	0.0272
37.4404	90	89.3695	0.6305
49.1677	0	-0.0015	0.0015
49.2003	15	14.989	0.011
49.3186	30	29.9701	0.0299
49.5441	45	44.9538	0.0462
49.1949	60	59.9198	0.0802
46.3287	75	74.8438	0.1562
44.3292	90	87.7647	2.2353

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Voltage_Sag_ Magnitude InPercent	Actual POW	POW initiation By Fundamentl Equation Method	Errore
%	Degree	Degree	Degree
59.6228	15	15.0015	-0.0015
59.6951	30	29.9968	0.0032
59.8376	45	44.9971	0.0029
57.6892	60	59.9855	0.0145
54.6845	75	74.9728	0.0272
52.6349	90	89.3695	0.6305
70.1844	0	-0.0052	0.0052
69.892	15	14.9952	0.0048
69.3564	30	29.9924	0.0076
69.1209	45	44.9927	0.0073
66.6308	60	59.9923	0.0077
63.7376	75	74.9847	0.0153
61.8657	90	89.4664	0.5336
79.7741	0	-0.0052	0.0052
79.5191	15	14.9952	0.0048
78.9733	30	29.9924	0.0076
78.5131	45	44.9927	0.0073
76.7085	60	59.9923	0.0077
74.3092	75	74.9847	0.0153
72.8989	90	89.4664	0.5336

Conclusion

It is proved that Point-on-wave initiation is the characteristics, which cannot be identified from RMS plot as well as from DWT method implemented in [8]. This is a characteristic that can be an “instantaneous sag characteristics”, which can be identified on the instantaneous voltage waveform plot.

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